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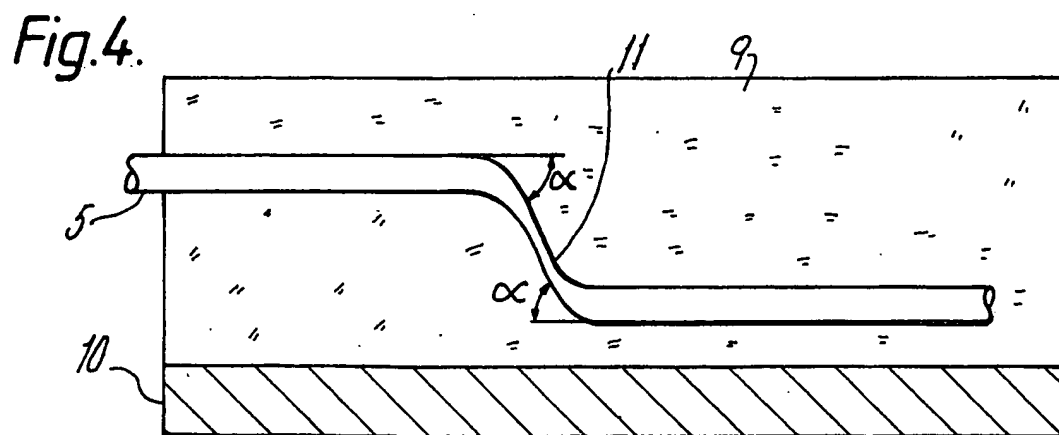
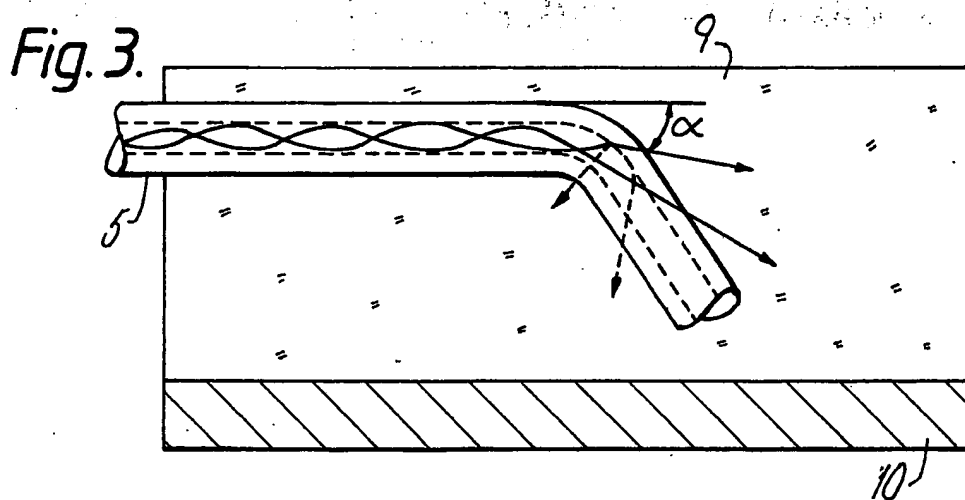
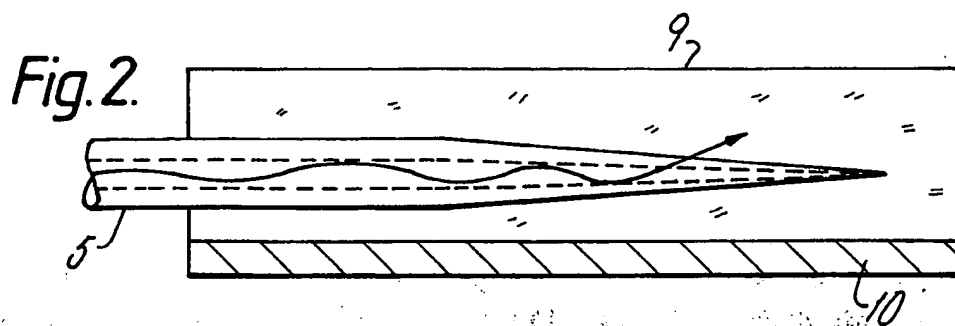
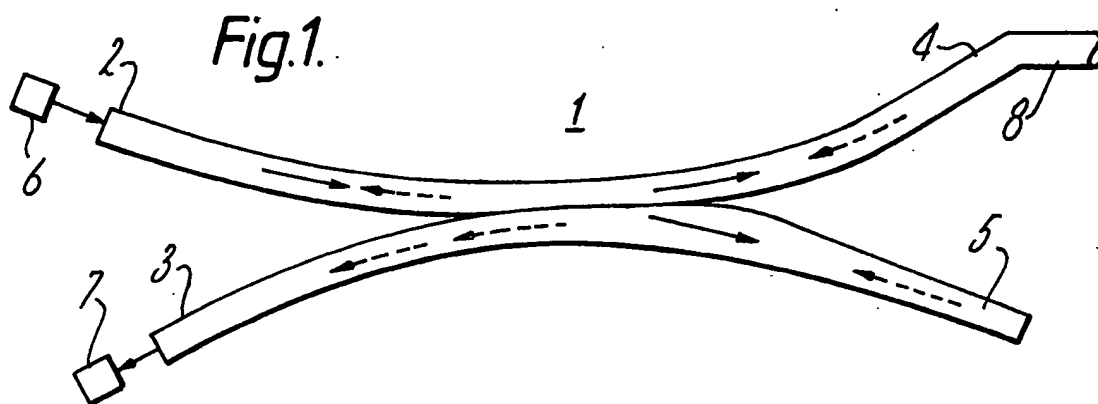
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(54) Optical coupler

(57) A three-port optical coupler for a two way optical fibre transmission system incorporates a four-port directional coupler 1 one of whose limbs 5 is terminated in a reflection

free manner provided by a local modification of the fibre geometry, for instance by a bend or a taper, to render it optically leaky, and by embedding this region in a medium whose refractive index is not less than that of the optical cladding of the fibre.

GB 2 124 403 A



## SPECIFICATION

### Optical coupler

This invention relates to an optical coupler incorporating a four-port optical fibre directional coupler, that is a four-limb optical fibre structure whose limbs are optically coupled in a manner providing the characteristic that light launched into the structure via any one of the limbs emerges from the structure via two of the other limbs. In particular the invention relates to an optical coupler in which one limb of the optical fibre directional coupler is terminated in a reflection free manner.

One such coupler is known from the article entitled 'Birdirectional Optical Link' by K. Koester and F. Mohr appearing in *Electrical Communication* Vol. 55 No. 4 pp 342—9 (1980), where it is used in a communication system requiring the simultaneous transfer of data in both directions over a single optical fibre link.

According to the present invention there is provided a three-port optical coupler incorporating a four-port optical fibre directional coupler one of whose limbs is terminated in a reflection-free manner provided by a local modification of the geometry of the fibre of that limb to render it optically leaky and the embedding of locally modified geometry portion in a medium whose refractive index is not less than that of optical cladding of the fibre of that limb.

There follows a description of optical couplers embodying the invention in preferred forms. The description refers to the accompanying drawings in which:

Figure 1 shows schematically that part of an optical coupler, whose directional coupler is of a bi-conical type, excluding the reflection free termination of one optical fibre limb, and

Figures 2, 3 and 4 show alternative forms of reflection free termination for one of the limbs of the device of Figure 1.

The article to which previous reference has been made, and to which attention is directed discusses two basic types of four-port directional coupler, one being a bi-conically tapered coupler type, and the other being of a type in which optical coupling between the fibres is effected by means of a partially transmitting mirror. For the sake of example, Figure 1 depicts a directional coupler of the former type, but it should be clearly understood that the terminations of Figures 2, 3 and 4 can be satisfactorily employed with either type.

Figure 1 schematically shows an optical coupler incorporating a four-port directional optical fibre coupler 1 of the bi-conical taper type, but omitted from this Figure is the reflection free termination of one of the four limbs of the directional coupler which renders the overall coupler a three-port device. The directional coupler is made from two optical fibres respectively having ends 2 and 4, and 3 and 5. These fibres may be single- or multi-mode fibres. A portion intermediate the ends of the two fibres

is drawn down in diameter to produce tapers in which the reduction of optical core diameter of the fibres produces an expansion of their evanescent fields so that they become optically coupled.

The end 5 of one of the fibres terminates in a reflection free manner in a structure not depicted in Figure 1, but which is one of the alternative structures depicted in Figures 2, 3 and 4. By way of example the other end of that fibre, end 3, is connected to an optical receiver 7, while the ends 2 and 4 of the other fibre are connected respectively to an optical transmitter 6, and an optical fibre transmission link 8 connecting this optical coupler with a remote optical coupler of similar type (not shown).

The course of the light as radiated by the optical transmitter 6 is indicated by the solid-line arrows, and the course of the light coming from the optical waveguide is indicated by the dash-line arrows in the directional coupler 1. If no reflection suppression arrangements were made at the end 5, the light from the transmitter 6 would be reflected at this end, and the course taken by this reflected light is indicated by the dotted-line arrows. Only the portion of this reflected light that reaches end 3 would be a nuisance because here it would be superimposed upon the weak incoming light from the optical fibre transmission link 8 and cause an unwanted crosstalk (signal interference).

In Fig. 2 the end 5 is shown partly sectionally in a first example of a reflection-free termination. The end section of the optical fibre is conically tapered and embedded in a sealing compound 9. The embedded coupler end 5 is arranged in an elongated half shell 10 consisting of quartz, or else of an opaque material, such as metal, in cases where light from outside sources is to be prevented from entering. The course of the incoming light is indicated by a long, continuous arrow. Within the conically tapered section of the coupler end, the light is forced out of the core area of the optical fibre into the cladding and is radiated towards the outside. Here it is absorbed by the sealing compound 9.

The sealing compound 9 must have a refractive index not less than the index of the optical cladding of the fibre, and must be capable of absorbing the light entering therein. As a suitable sealing compound there may be used a filled two-component adhesive based on epoxy resin. The sealing compound should not contain any reflecting fillers. As the sealing compound 9 there may also be used a black lacquer into which the tapered fibre end section 5 is immersed. A sealing compound 9 containing black fillers, such as an epoxy-resin adhesive (e.g. "Epotek 320" of Epoxy-Technologie) may also be used.

The conical taper of the fibre end section 5 can be produced by clamping the fibre in a drawing jig, then locally heating it and drawing it to obtain a pointed end.

The elongated half shell 10 can be produced in a

simple way by longitudinally cutting a tube into half.

Fig. 3 shows a second example of embodiment of a reflection-free terminated fibre end section 5 partly in a sectional representation. The end of the optical fibre is provided with a bend whose angle of bend  $\alpha$  must be greater than double the maximum angle of propagation inside the fibre.

$\alpha \geq 2 \arcsin \text{N.A.}$ , wherein N.A. is the numerical aperture of the optical fibre. It is preferred to provide an angle of bend  $\alpha$  ranging between  $30^\circ$  and  $60^\circ$  which is easy to produce. Under this condition, the light travelling inside the optical core of the fibre, whose course is indicated by long, continuous arrows, is forced to radiate within the area of the bend, into the optical cladding of the fibre. From there, as already described hereinbefore, it radiates into the absorbing sealing compound 9 in which the fibre end section 5 is embedded. Any light reflected at the boundary or interface between the cladding and the sealing compound 9, whose course is indicated by the dashline arrows, is slantingly deflected and then absorbed by the surrounding sealing compound 9.

As already mentioned hereinbefore, the bent fibre end section 5 as embedded in the sealing compound 9, is arranged inside a half shell 10.

The bend in the optical fibre can be produced in the following way:

The optical fibre is aligned at an angle inclined to the vertical at one end in a clamping jig and locally heated about 1 cm away from the end. For this purpose there may be used a micro-torch or else an electric arc. Gravity then causes the free end to drop down into a vertical orientation, thus forming a bend whose angle typically lies in the range from  $30^\circ$  to  $60^\circ$ . The free end of the bend may be cut short so that the coupler end 5 can be inserted in the half shell 10 and embedded in the sealing compound 9.

Fig. 4 shows a third example of a reflection-free terminated fibre end section 5 partly in a sectional representation. The end of the optical fibre is provided with two bends between which there is provided a tapered region 11. The angles of bend again, as in the second example of embodiment, are in the order of  $\geq 2$  arcs in N.A., with also in this case angles of bend ranging between  $30^\circ$  and  $60^\circ$  having proved favourable.

As already described hereinbefore, the light as guided in the optical fibre end section 5 is forced to radiate out of the first bend and is absorbed by the surrounding sealing compound 9. The tapered region existing between the bends, additionally assists in the outward radiation of the light. Any light still being further guided is forced by the second bend to radiate out of the optical core and is absorbed by the sealing compound 9.

Here, too, the fibre end section 5 is inserted in the half shell 10 and then embedded into the sealing compound 9. Owing to the double bend,

this design of reflection-free termination requires less space.

65 This double bend in the optical fibre end section 5 can be produced in the following way:

The optical fibre is inserted and retained at both ends in a clamping jig capable of being aligned in a x—y—z direction, and is then displaced at one end vertically in relation to its axial direction by about 1 mm, and thus pretensioned. The fibre is then heat softened in a region approximately midway between the two holding points there is then effected a heating of the optical waveguide. The tension inside the fibre is thereby enabled to be relaxed by the formation of a double bend with a tapered region 11 therebetween. The free end of the fibre is then cut short and, after having been placed into the half shell 10, is embedded in the sealing compound 9.

### Claims

1. A three-port optical coupler incorporating a four-port optical fibre directional coupler one of whose limbs is terminated in a reflection-free manner provided by a local modification of the geometry of the fibre of that limb to render it optically leaky and the embedding of locally modified geometry portion in a medium whose refractive index is not less than that of optical cladding of the fibre of that limb.

2. An optical coupler as claimed in claim 1 wherein the four-port directional coupler is of the bi-conical taper type.

3. An optical coupler as claimed in claim 1 or 2 wherein the modified geometry portion of fibre consists of or includes a bend through an angle larger than twice the maximum angle of propagation inside the fibre.

4. An optical coupler as claimed in claim 3 wherein the modified geometry portion of fibre consists of a double bend with a bi-conically tapered portion between the two bends, wherein each bend is through an angle larger than twice the maximum angle of propagation inside the fibre.

5. An optical coupler as claimed in claim 3 or 4 wherein the or each bend is through an angle lying in the range from  $30^\circ$  to  $60^\circ$ .

6. An optical coupler as claimed in claim 1 or 2 wherein the modified geometry portion of fibre consists of a taper.

7. An optical coupler as claimed in any preceding claim wherein the embedding medium is a resin.

8. An optical coupler as claimed in claim 7 wherein the resin contains a black filler.

9. An optical coupler as claimed in claim 7 or 8 wherein the resin is a two-port epoxy resin adhesive.

10. An optical coupler as claimed in any preceding claim wherein the embedding medium is contained in an elongated half shell.

11. An optical coupler as claimed in claim 10 wherein the shell is made of quartz.

12. An optical coupler as claimed in claim 10  
wherein the shell is made of metal.  
13. A three-port optical coupler substantially

as hereinbefore described with reference to the  
5 accompanying drawings.

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